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How Structures Withstood the Japanese Earthquake and Fire

BY

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One of the papers presented at the Twentieth Annual Convention of the American Concrete Institute held in Chicago, February 25-28, 1924

FOREWORD

Soon after the great earthquake that occurred in Japan on September 1, 1923, reports of its effect on structures appeared in the Semi-Technical Press. These early accounts, however, fell short of presenting actual facts about what really happened.

In order to obtain reliable information about the effect of this great catastrophe on buildings, the Portland Cement Association sent H. M. Hadley, a Structural Engineer of wide experience, to Japan for a two month's study of the situation. The paper reprinted in this booklet constitutes Mr. Hadley's complete report. It is hoped that this report may be of value to designers in making buildings safe against the effects of natural forces of unusual violence.

It is well known that destructive earthquake shocks may be expected only in certain localities. However, a study of the effects of the Japanese earthquakes reveals much of interest and value regarding how to design buildings to withstand such agencies as tornadoes, hurricanes, yielding of foundations or other causes producing horizontal or vertical motions of the whole or a part of a building.

Authorized reprint from the copyrighted *Proceedings* of
AMERICAN CONCRETE INSTITUTE
Vol. 20, 1924

REPRINTED FOR
PORTLAND CEMENT ASSOCIATION

HOW STRUCTURES WITHSTOOD THE JAPANESE EARTHQUAKE AND FIRE

BY H. M. HADLEY*

At noon on Saturday, Sept. 1, 1923, there occurred a great earthquake in the east central portion of the main island of Japan, which earthquake in its destructive consequences, is one of the worst recorded in human history. The earthquake itself wrought tremendous instant damage. Structures of all kinds that were deficient in foundations or rigidity broke and fell, bridge piers were overturned, tunnels were blocked, landslides swept down mountains, many thousands of people were killed, and vast havoc was caused. This was but the beginning, however. Occurring at the hour of noon when dinner was being prepared in many houses in Yokohama and Tokio, the collapse of weak structures, particularly the collapse of light-framed wooden Japanese houses, started simultaneous fires in many places, the building department of Tokio reporting that 74 separate and distinct fires started a few minutes after the first destructive shock with a total of 140 original fires, of which 15 were explosive, 85 from stoves (hibachis) and 40 from sparks. Water mains and supply lines had been broken, many streets were choked with debris, fallen wires, abandoned vehicles, etc., and the densely built up cities consisting principally of wooden construction interspersed with brick buildings, and less frequently with buildings of reinforced concrete or structural steel frames, practically all without fireproof openings or details, stood as so much fuel for fire. Fire came. Conflagrations swept the cities, practically wiping out Yokohama, destroying about 50 per cent. of Tokio, including the major part of the business district, and consummating the great disaster.

No exact estimate of the damage is possible. One estimate gives 80,000 human beings killed and 140,000 missing. Of the missing undoubtedly many thousands were killed. Property of vast value was destroyed, probably four to five billion dollars worth. There is the further loss that cannot be evaluated of demoralization of business and loss of records, etc., etc. The Japanese Empire was dealt a very heavy blow.

The Japanese islands constitute a region in which earthquake activity is more frequent and pronounced than anywhere else in the world. Hundreds of quakes occur annually, although the great majority are so slight as to be almost imperceptible. At varying intervals in past history, have occurred earthquakes of magnitude equal to or greater than this one, but this earthquake is the first in Japan to severely test modern building construction.

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Various observations at different stations agree in locating the origin of this present earthquake in Sagami Bay. Whether the cause be volcanic or tectonic, a great buckling of the earth's crust occurred at this point. Preliminary soundings taken between Oshima Island and the southwest shore of Sagami Bay, reveal a 300 ft. uplift in the bottom of the bay at what had formerly been the point of maximum depth, accompanied by a 600 ft. settlement, below its former depth, of the bottom on both sides of this newly uplifted portion.

Incompleted surveys show marked changes in the elevation of the shores surrounding Sagami and Tokio Bays. Extensive uplifting of 12 to 15 ft. has occurred in places with less uplift or sometimes settlement elsewhere. The tremors and vibrations set in motion by these great crustal changes are what constitute the disastrous earthquake of Sept. 1, 1923.

Regarding the character of destructive earthquake vibrations, the following is condensed from a paper written by the late Dr. F. Omori. The complete earthquake motion is composed of several sets of waves of different transit velocities and different lengths of vibrational period. Due to the more rapid dissipation of energy in the waves of shorter period, it depends on the distance of the observing point from the origin of the quake, which of the several sets of waves is the most pronounced and produces the maximum vibration. Maximum waves from a distant origin have an average period of 20 seconds; from a comparatively near origin (the example given has a distance of 2070 km. = 1286 miles), a period of 8 seconds; and from a near origin, a period of from 1 to 2 seconds; generally being 1.5 seconds. Waves of the first two classes are imperceptible without instrumental aid. Waves from a near origin and of short period are classified as longitudinal and transverse, the former and more rapid moving directly in the line from the subterranean origin to the point of observation; the latter and slower moving normal to the plane determined by the point of observation, the origin, and the epicenter, i. e., the point on the earth's surface vertically above the origin.

It is the period between the arrival of the longitudinal and transverse waves—that is, when only the longitudinal waves are felt—that constitutes the preliminary and minor phase of an earthquake. It is the transverse waves, which have in general, only a small vertical component, that produce the shocks of maximum intensity. Even in districts that have been situated directly above the origin of severe earthquakes, the evidence shows much greater damage from the transverse or horizontal vibrations than from the longitudinal, which in any epicentral zone are vertical. Observation shows that for a given period, the amplitude of vibration of the maximum transverse wave reduces inversely as the square of the distance from the origin, or even more quickly, depending upon the character of the intervening material.

From another of Dr. Omori's papers, published in 1900, the following is quoted: "In ordinary cases the vertical component of earthquake motion is much smaller than the horizontal. Thus in the severe Tokio earthquake of June 20, 1894, the strong motion seismograph in the

Seismological Institute, recorded a maximum horizontal motion of 73 mm. (period 1.8 seconds) while the maximum vertical motion was only 11 mm." * * * * "I may here note that earthquake motion, though sometimes very violent, is continuous and does not consist of isolated jerks or shocks. The idea prevalent among certain engineers that in destructive earthquakes, buildings are first uplifted by the vertical motion and are then destroyed by being suddenly thrown downward, is quite erroneous."

For the determination of the dynamic effect of earthquakes upon structures, the customary seismological measurements of time and 3-dimensional movement forms the basis. The unknown, unmeasured quantity is the velocity of motion at different points in the path of the earthquake wave.

The diagram herewith shows a graphical representation of one complete earthquake wave. Actually the points 0 coincide, but they are shown separated to illustrate the assumption which is made: namely, that in

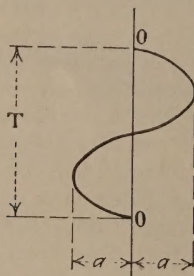


FIG. 1.—THEORETICAL EARTHQUAKE OSCILLATION.

going from 0 to 0 the motion is harmonic; that the velocities along the path vary as the sines of the angles formed by a point moving at uniform velocity around a circular path in the period T . Under this assumption the maximum velocity of the earthquake wave occurs at the points 0, while the maximum acceleration occurs at the extremities of the path. Whence, mathematically,

$$\text{Max. Acceleration} = \frac{4a\pi^2}{T^2}$$

and F , the dynamic earthquake effect, the earthquake force on structures =

$$\left(\frac{4\pi^2}{g} \right) \left(\frac{a}{T^2} \right) \left(W = \text{weight of structures.} \right)$$

On September 1 at the Seismological Institute at the Imperial University, Tokio, the most severe shock had an amplitude of 10.3 cm. (4 m) in a period of $1\frac{1}{2}$ seconds, of which the dynamic effect was, according to the above formula almost exactly $1/11 W$. Greater motion occurred in later shocks, approximately 6 inches, but the time interval was greater and the first named shock was the maximum in so far as its effect on buildings and

structures is concerned. This observatory is situated on the high firm ground of the city where the motion was not so great as in the low lying business area. The observatory's estimate of the motion in the low lying ground is from two to three times that at the observatory, and they estimate that the severity of the shock at Yokohama was three to three and a half times that at the University.

If a glass of jelly be turned into a dish and the dish be shaken gently, relatively great motion of the jelly will ensue. This behavior is illustrative of the effect of earthquake vibrations in firm and soft ground. The



FIG. 2.—SUMITOME WAREHOUSE—TOKIO.

West and South elevations. 180 x 200 ft. high. Filled with heavy storage valued at \$4,000,000 at time of earthquake.

wave amplitude in firm material may be increased several-fold if the overlying ground be soft, spongy or marshy. This fact has an important bearing on the Yokohama-Tokio disaster.

These cities are both situated on the west shore of Tokio Bay; Tokio at the head of the bay and Yokohama, 18 miles distant, at the head of deep water navigation. From Yokohama southward the low irregular hills rise steeply from the water's edge, in some cases cut by waves into bare abrupt bluffs, one hundred or more feet high. These hills are of recent geologic origin consisting of horizontally stratified beds of clays, sands, and gravels, and combinations of these materials, not yet solidified into rock, and topped by a loosely compacted reddish-yellow earth of probably volcanic origin. From Yokohama northward to Tokio, the hills rise less



FIG. 3.—REINFORCED-CONCRETE WAREHOUSE AT HIGASHIKANAGAWA.
Wreck due to foundation settlement.



FIG. 4.—CASCADE BREWING CO.—TSURUMI.
Reinforced Concrete. Only minor damage done to main building shown in photograph.

abruptly and more gradually to the higher levels behind and except at a few points do not lie close to the shore, since the silting up of the upper bay by the discharge of several rivers and other geologic processes have built up a low flat marginal plain of varying width between the hills and the present water's edge. Extensive areas have been filled and reclaimed at various times at Tokio, Yokohama and intermediate points, and most of the destroyed areas in both Tokio and Yokohama were situated on this low-lying ground. Particularly in Tokio, the boundaries of the fire-swept districts closely coincided with those of the low-lying ground on which the great majority of modern buildings were located.



FIG. 5.—REINFORCED-CONCRETE GRAIN ELEVATOR AT HIGASHIKANAGAWA.

In this stage of construction when earthquake occurred. One of the largest reinforced concrete structures in earthquake zone. Practically undamaged. Good pile foundations.

While the earthquake in some instances damaged certain buildings and left other nearby ones untouched, this is not, as is sometimes suggested, to be regarded as a vagary in the occurrence of the shock. In any given district where soil conditions were identical throughout, it is practically certain that the shock was everywhere of consistent performance, and differences in damage are to be attributed to differences in the structures themselves. Also the speed of propagation of the earthquake motion is so great that except as results of local fissuring and cracking of the ground, no differential shaking of buildings can be supposed, i. e., any structure would be affected equally and simultaneously in all its parts.

Building construction in Japan is represented by structures of all characters, those of the type of the ancient empire, shut off from intercourse with the outer world, of course, predominating, but modern structures of steel and reinforced concrete are numerous and are being built in ever increasing numbers. Reinforced concrete had been used in Tokio for some fifteen years; structural steel about five. Brick had been used extensively for many years in the construction of stores, dwellings, factory buildings, etc., while wood and stone masonry had been used for centuries and it was in these last named materials that Japanese architecture had found its own characteristic and individual expression.



FIG. 6.—PHOTO SHOWING GENERAL DESOLATION AT YOKOHAMA.
Russo-Asiatic Bank Building.

Common to all types of buildings is the necessity for good foundations. Without full and adequate support no structure could be expected to stand and no structure did. There has been considerable discussion regarding the merits of mat and pile foundations. Either is satisfactory so long as unyielding support is obtained. Inasmuch as the severe earthquake motion is predominantly horizontal, the cushioning effect which it is claimed can be obtained with mat foundations is a cushioning not in the direction of the severe forces. On the other hand, where mat foundations do not have piles beneath them carried to a depth sufficient to furnish full and unyielding support, very expensive damages may result from the bodily settlement of these mat foundations with their superimposed

building into the soft ground under the shaking effect of the earthquake. Where individual footings are used they should be connected with beams of sufficient strength to maintain them at all times in their normal relative positions.

Reviewing the behavior of structures of the several building materials under the test of earthquake and fire, the following summary can be made:

1. *Wood*.—In the fire-swept areas all evidence was destroyed. Elsewhere the performance was generally good. In Japanese houses where heavy tile roofs were carried by light wall posts with little bracing, more



FIG. 7.—KIRIN BREWERY—YOKOHAMA.

Photo shows undamaged reinforced concrete tower used for malt and hops storage.

or less racking with consequent cracking of plaster ensued and, of course, there were numerous collapses of buildings inadequately braced and stiffened. The Japanese are skillful carpenters and their houses are framed with mortise and tenon joints and wooden pins, etc. The combination of great strength with light weight that is the inherent character of wood, is most advantageous in structures subjected to earthquake shocks. At the same time the problem of efficient joints and connections becomes increasingly important. Two of the finest examples of wood construction are to be seen at an industrial plant at Kawasaki, where two buildings of reinforced concrete collapsed and a third was badly damaged. These buildings had been designed by an American architect who had an adequate concep-

tion of the forces to which these buildings might be subjected. Consequently all connections between beams and the columns which were closely spaced in one direction, had been knee-braced and well bolted and washers of generous size were used. At each of the three floors the buildings were trussed horizontally at all four walls and at all four corners vertical trusses in the plane of the side walls extended from the foundations to the roof. These buildings, full of valuable machinery, escaped without the slightest damage.

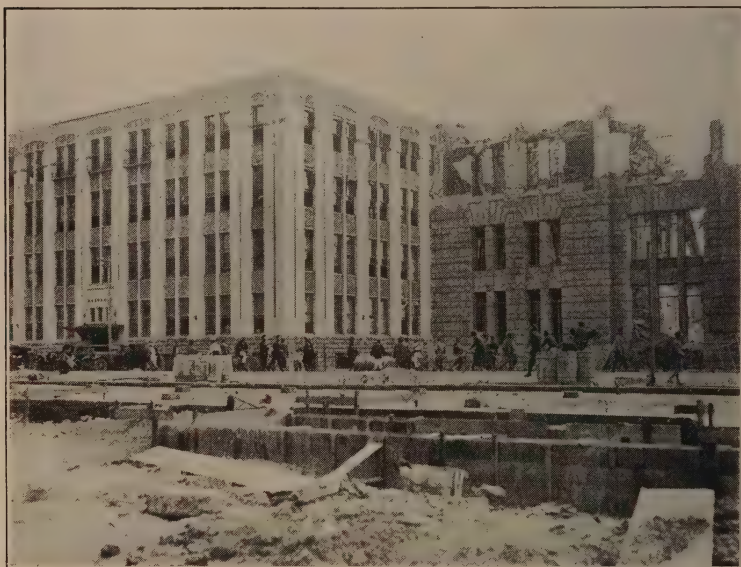


FIG. 8.—ABSOLUTELY UNDAMAGED REINFORCED-CONCRETE BUILDING ON BLOCK IS MARUNOUCHI CENTRAL, TOKIO.

2. *Brick.*—Regarding brickwork, it should be stated at the outset that practically all construction is with Japanese brick, of a strength no greater and probably weaker than American common brick. Mortar undoubtedly varied greatly in quality but the execution and workmanship of laying up brickwork is probably superior to American. In the vast amount of shattered brickwork fractures in general occurred through the brick itself and not along the mortar joints and also revealed the inner mortar joints well filled and without voids or holes. Construction of buildings generally in Japan is a more slow and deliberate process than in America, and workmanship can be correspondingly more thorough and careful.

With certain splendid exceptions, brick failed badly and was responsible for great loss of life. The following is from the report of K. Satch, Structural Engineer of the Tokio Building Department, who was in charge

of the investigation of 485 brick structures in Tokio, 49 of which were situated on the relatively firm higher ground, and 436 on the low lying ground. Needless to observe, the percentages based on the low ground buildings are more representative than the high ground, since nine times as many buildings are under consideration.

Districts.	Entirely Collapsed.	Partially Collapsed.	Heavily Damaged.	Slightly Damaged.	Undamaged.	Total.
Yamanote (hard soil).....	3	9	15	16	6	49
Shitamachi (soft soil).....	44	104	87	120	81	436

Showing the above figures by percentages:

Yamanote.....	6.0	18.4	30.6	32.7	12.3	
Shitamachi.....	10.0	23.9	20.0	27.5	18.6	



FIG. 9.—TEMPORARY QUARTERS OF YOKOHAMA SPECIE BANK.

Reinforced concrete and brick filler walls. Damage due to brick filler walls.

Fundamentally the weakness of brick masonry is its low tensile strength which is insufficient to withstand the bending and swaying that an earthquake causes unless the walls be of considerable thickness and be well stiffened by the floor systems or heavy division walls.

3. *Structural Steel*.—As stated, the use of structural steel for building purposes is very recent in Japan. Nevertheless numerous large structures had been completed and others were in the course of erection, when

the earthquake occurred, and these buildings were sufficiently numerous and varied in character to permit conclusions to be drawn regarding their behavior. It is unnecessary to enumerate the known excellences of structural steel, although the severe property losses that occurred in the burned areas from its use without any fire protection emphasizes the necessity for properly safeguarding it. What is the outstanding and unusual feature of skeleton steel framed buildings under earthquake conditions is their tendency to rock and sway. The sudden quick motion of the ground produces a correspondingly sudden bending and deformation of the steel columns



FIG. 10.—PATENT OFFICE EXHIBITION BUILDING—TOKIO.

Rear North Elevation. Reinforced concrete. Failure due to inadequate foundations causing a 2-ft. settlement.

and the horizontal load is thrown upon the stiffer vertical members of the structure: the exterior walls, interior partitions, stair and elevator enclosures, etc. Whereupon these secondary vertical members, unless they possess adequate power of resistance, are broken and shattered, and thereafter the resistance is furnished by the structural steel alone, when on the other hand the wall construction possessed the adequate power of resistance no damage was entailed, the buildings standing rigid and unyielding. Four large completed steel frame buildings in Tokio and two practically completed escaped without damage from the earthquake. The common characteristic of all of these buildings was their complete or extensive use of reinforced concrete wall construction. These buildings are the Industrial

bank of Japan, the First Mutual Building, No. 21 Mitsubishi, and the building of Katakura & Company. These were completed and occupied. The two under construction were the Marumouchi Hotel and the Kokko Life Insurance Co. Building. These buildings all escaped with absolutely no damage. They were the only large steel frame buildings in Tokio which did. On the other hand, the 11 other large steel frame buildings which employed brick for their wall construction all sustained more or less damage due to the shattering of their exterior walls, breaking of interior par-



FIG. 11.—INTERIOR VIEW SHOWING BADLY DAMAGED FIRST STORY COLUMN IN BUILDING NO. 25 OF INDUSTRIAL PLANT AT KAWASAKI

Shows absence of spiralling and very light binders.

titions, destruction of marble trim and wainscoting, damage to elevators, etc. One other large building had its structural steel frame completed and concrete wall construction started in the lower stories, but this building was not sufficiently advanced in its wall work to serve as proof of the merits of concrete wall construction for resistance to earthquake. Three other buildings, the Sumitomo Bank, the Mitsubishi Bank, and the main Central Railway Station were of structural steel and heavy brick or stone masonry. These were all rather low structures, however, and are not to be classed with those previously mentioned. Outside of Tokio no large structural steel frame buildings of the above character existed in the earthquake region. A number of industrial plants had mill and shop buildings

of structural steel which behaved in an entirely satisfactory manner when adequately braced and not exposed to fire.

A general survey of the situation leads to but one conclusion: Properly designed structural steel buildings, well braced and thoroughly fire-proofed can be made earthquake-proof; the simplest, cheapest and most efficacious bracing can be secured by making the wall construction of reinforced concrete.

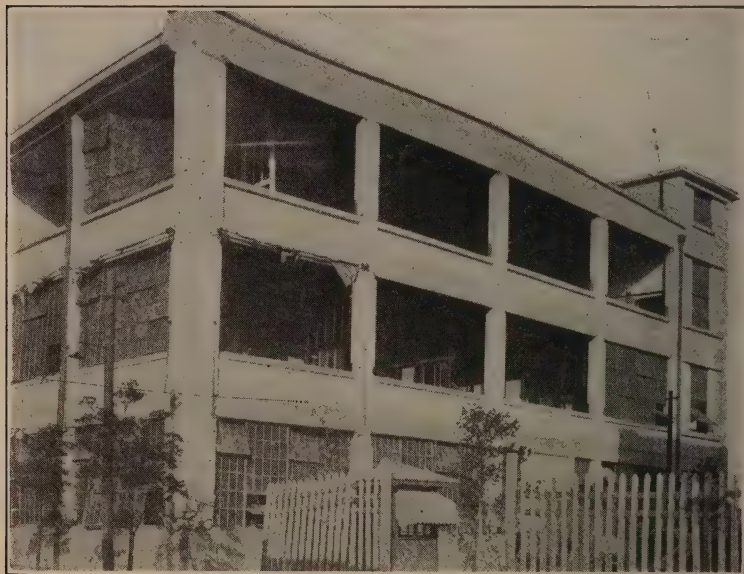


FIG. 12.—BUILDING NO. 18, INDUSTRIAL PLANT AT KAWASAKI, BETWEEN TOKIO AND YOKOHAMA.

Reinforced concrete. Damage caused by poor foundations and lack of rigidity.

4. *Reinforced Concrete*.—The performance of reinforced concrete under the test of earthquake and fire can only be classed as highly satisfactory. A survey of reinforced concrete construction in Tokyo Prefecture conducted by the Tokyo Building Department under the direction of Mr. Y. Nagata, Chief Engineer, resulted in the following findings:

	Entirely Collapsed.	Partially Collapsed.	Greatly Damaged.	Partially Damaged.	Undamaged.	Total.
	8	11	42	69	462	592
Percentage of total.....	1.3	1.9	7.1	11.7	78.0	100.0

I questioned Mr. Nagata closely regarding the exact meaning of the terms of his classification, that are perhaps indefinite. Regarding "Entirely

Collapsed" and "Partially Collapsed" there can be no uncertainty. "Greatly Damaged" he illustrated by two buildings: The Hoshi Drug Building and the Industrial Club of Japan. "Partially Damaged" means without severe damage to structural frame, although the walls may be shattered. He gave me as examples of this classification the following structural steel framed buildings, Tokyo Kaijo, N. Y. K. Maranouchi, and Yuraku. "Undamaged" includes cases of minor cracking of walls, but no damage to structural frame. The Sumitomo Warehouse illustrates this classification. As stated this survey includes damage by fire. Warehouses classed as par-



FIG. 13.—POWER PLANT AT HIGASHIKANAGAWA.

Reinforced concrete boiler house. Failure due to faulty engineering design. Heavy roof was not anchored, tore free from the columns and fell.

tially collapsed would shift to the undamaged classification were the earthquake alone considered and there are several other buildings which would be similarly changed.

Elsewhere in Tokyo Prefecture the results obtained were as follows, this damage being solely by earthquake:

	Entirely Collapsed.	Partially Collapsed.	Greatly Damaged.	Partially Damaged.	Undamaged.	Total.
	8	9	7	5	89	118
Percentage of total.....	6.8	7.6	5.9	4.2	75.5	100.0

In giving me this information, Mr. Nagata told me it was preliminary, and subject to change and correction, but substantially was correct; changes to be minor only.

Considering all things, this is a highly satisfactory performance. Particularly is this true when the character of concrete in this district of Japan is known. No criticism can be made of the character of Japanese cement used in this district, but their aggregates as used would be summarily rejected in any construction work in this country. The sand itself is quite fine, of uniform size and of indifferent structural quality. The



FIG. 14.—MITSUI NO. 3 BUILDING—TOKIO.

North and West elevations. Reinforced-concrete—110 ft. high. Guttured by fire—uninjured by quake. Debris in foreground from adjoining brick structures. Concrete stack at left on Mitsui No. 4 Building.

greatest trouble results from the coarse aggregate. This is river gravel of fair strength which is dug by hand from river bars. It is used in the condition in which it is dug, all particles being coated with silt, and with an admixture of about 25 per cent sand in the gravel. A composite sample taken from six different building jobs under construction in Tokyo showed the following results: Gravel contained 11/10 per cent silt in the coatings; sand contained 1½ per cent silt; organic plate No. 2. Seven-day briquettes 85 per cent of Ottawa; 28-day briquettes 89 per cent of Ottawa. Average compressive strength of six 4 x 8 cylinders stored 28 days in damp sand at 70 degrees F., 1103 pounds per square inch. With a division of



FIG. 15.—POWER PLANT AT OIMACHI.



FIG. 16.—NICHU NICHU BUILDING—TOKIO.

Reinforced concrete. No damage.

material on the $\frac{3}{4}$ inch screen the 1:2:4 mix which they so extensively employ would be actually a 1:3:3. With excess of water and poor curing it is unlikely that their building concrete possesses a strength more than 800 or 900 pounds per square inch. Nevertheless, it is concrete of this character which performed as the above surveys show. It can only be expected that with really good concrete, a far better record would have been established.



FIG. 17.—JUTSUGYO BUILDING.

South and West elevations. Reinforced concrete, veneered with Japanese tile. Had recently been completed at time of earthquake.

Causes of Failure.—The only good that can result from a disaster of this character is the lesson that is to be learned from it. In the field of concrete where failures occurred they were due to one or more of the following conditions:

1. Inadequate foundations; 2. Violations of commonly accepted principles of engineering design; 3. Lack of rigidity in buildings. The third cause is the feature that is peculiar to earthquakes. The small one story market building at Yokohama shown in photograph No. 400 was 75 x 300 ft. in plan with 25 ft. square bays, was unusually well built, was thoroughly reinforced and the reinforcement was all fully anchored and hooked and no sign of foundation trouble was to be seen. Nevertheless, lacking

rigidity, lacking resistance to the bending stresses developed by the sudden horizontal motion of the ground on which the structure stood, it failed. How this stiffness is to be obtained is the problem of earthquake-proof construction. The solution is to make part or all of the wall construction of



FIG. 18.—OKURA & CO., LTD., BUILDING, TOKIO.

Reinforced concrete—veneered with Japanese tile and stone.

reinforced-concrete integral with the columns. This is but another way of saying to increase the dimensions of certain columns, since the introduction of a duly designed reinforced-concrete wall between and integral with two columns makes them act as one column, with a resistance to bending many times greater than that which the two separate columns formerly possessed. For example, a row of ten 1-ft. square columns 10 ft. on centers would

have a resistance to bending in the direction of the row which is a function of the square of the depth of the columns and may be represented by 10. The introduction of a reinforced-concrete wall between two of these columns would make a single column of the two, which single column would have



FIG. 19.—KASHIMA BANK BUILDING—TOKIO.

Reinforced concrete. Burned by fire. Undamaged by quake.

a resistance to bending equal to 11^2 or 121 . To secure equal resistance by increasing the size of each individual column would require that they be made 3 ft. 6 in. each.

The one story market building of photograph No. 400 had open walls between the wall columns. The introduction of 10 ft. wall sections at all four corners—points where the sacrifice of light is a minimum—and of

small sections of wall perpendicular to the length at one or two points, would have unquestionably saved this building. How much wall is needed for any design is simply a question of the weight of the structure and the earthquake forces, which acting in any direction, must be designed for



FIG. 20.—MITSUI NO. 4. BUILDING.

Reinforced concrete. Gutted by fire. Undamaged by earthquake and does not have a crack in it.

Where, as in certain buildings, it may be undesirable to use walls, then equivalent stiffness must be developed by trussing or by frame action. The use of relatively small diagonals for tension members in conjunction with the regular beams and columns of a building, would accomplish the desired result with a maximum of opening.

Regarding the special features of Japanese reinforced-concrete design, the most noteworthy is the care given in their best practice to adequately anchor all reinforcement. Footing stubs and column verticals are hooked at the splices and all possible anchorage for all bars is secured. With the reversal of stress that accompanies earthquake motion the advisability of this practice is manifest. Laps of column verticals are based on tension, not compression. An attempt to vary and stagger the plane at which horizontal construction joints in columns are made so as not to have all



FIG. 21.—MITSUBISHI HEAD OFFICE BUILDING—TOKIO.

Reinforced concrete—tile and stone veneer. Undamaged.

joints in the same plane, was also observed. I question the necessity of this in a structure of good concrete with joints kept free from laitance, wood and general dirt.

Wire mesh was used quite extensively for floor slab reinforcement. I noted that it was invariably in the bottom of the slab at supporting beams instead of at the top where it belonged. Whether this was intentionally or unintentionally misplaced, I do not know.

The use of metal lath between beams for combined forms and slab reinforcement was observed in two failures. This construction provides no continuity of reinforcement in beams, and there is a lack of strength in consequence.

The omission of slab reinforcement in a concrete joist job was likewise noted. This detail did not increase the strength of the structure. The omission of mesh reinforcement in fireproofing structural steel columns entailed disastrous consequences, in one or two instances, most strikingly in the case of the Mitsubishi warehouse at Tokyo. This was a large two-story warehouse of reinforced-concrete except for the interior columns which were angle latticed steel, fireproofed with two inches of concrete but without mesh. This building withstood the earthquake without any damage, but in the ensuing fire the concrete fireproofing spalled, the columns buckled, and the major portion of the building collapsed.

Of all structures of reinforced-concrete, chimneys gave the most unsatisfactory performance. There were many that successfully withstood the earthquake, but there were likewise many which failed, and in several instances caused great damage to structures nearby. The poor quality of the concrete revealed itself most plainly in these structures, where concrete of especially good quality is required.

Bridges of structural steel and reinforced-concrete gave entirely satisfactory performance when they received the support they deserved from piers and abutments. The 125 ft. skew arch on the Tokyo elevated railway, a short distance north of the Central railroad station, was entirely undamaged. Several steel bridges in the fire zone suffered damage to their floor systems where wood decks were used and wooden trestles likewise suffered damage from fire. One of the most disastrous failures was on the main line railway at the crossing of the Baniu River where a long steel plate girder bridge went down due to the overturning of brick masonry piers. Mention should be made of the admirable performance of the elevated railway construction in Tokyo. South of the station for two or three miles the track is elevated and carried on a series of brick masonry arches of 40 to 50 ft. spans, terminating in heavy abutments at the street intersections. This work stood perfectly. So likewise did a mile of reinforced-concrete elevated construction, north of the Central station.

Concrete retaining walls gave generally satisfactory performance. Foundation troubles were responsible for any damages which I observed.

Regarding tunnels, the only lined tunnel which I saw was through the Bluff at Yokohama, about $\frac{1}{4}$ mile long and was lined with brick. One portal was damaged by a landslide, but otherwise it escaped undamaged. On the main railroad lines through the mountains landslides blocked numerous tunnels.

In conclusion I would state that in general satisfactory performance was obtained only with structural steel or reinforced-concrete; that the concrete was of uniformly inferior character; that despite this fact its behavior was admirable; that skeleton construction with either material without bracing is inadequate; that firm and unyielding foundations are essential; that in building construction the use of reinforced-concrete walls is the simplest, best and cheapest insurance against earthquake damage.

THE American Concrete Institute is an organization of voluntary workers for the most intelligent and economical use of concrete in all its applications. Its membership includes architects, constructors, concrete products manufacturers, engineers and others, reports of whose researches and practical experience, and whose adopted standards of design and practice have in twenty years of the organization's work vastly influenced for good the whole broad use of concrete.

The Institute thus provides a comradeship in determining the best ways to do concrete work of all kinds and in spreading knowledge of these methods — a comradeship which is enjoyed by more than 1300 practical-minded students of the material throughout the world.

More detailed information regarding the organization's present activities in more than thirty technical committees, each studying a particular phase of the Institute's special work, and as to the Society's accumulated literature on concrete may be had upon inquiry of

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